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Declassified in Part - Sanitized Copy Approved for Release 2012/01/12 : CIA-RDP80T00246A018600710001-7

Influence of Non-uniform Base Width on Transistor Failures

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"Myterious" failures are often encountered, when transistors are operated in switching circuits, in spite of provisions made to prevent overload.

Collector-to-emitter shorts may suddenly develop although the emitter-base and collector-base diodes are still good. This phenomenon may be explained by the supposition that inside the transistor a p-type channel interconnecting the emitter and the collector appears in the n-type base region. /These considerations hold for p-n-p transistors/.

The narrow channels, causing shorts, have been microscopically detected inside the damaged transistors.

The channel is the result of localized heating phenomena, due – in accordance with the author's observations – to the non-uniform base width of the transistor.

With a transistor base width considerably reduced at a certain spot, current density will rise locally owing to an increase in hole density. The elevated current density results in a growth of temperature at the corresponding emitter and collector points, respectively. The overheating of the emitter points gives rise to the increase of the hole density in the minimum-base-width region. Thus the gradient of hole density is further increased, resulting in an even higher current density. It is obvious that this process is regenerative, involving a thermal feedback loop.

The effects described are of importance especially during the sw... ...er times, because a considerable momentary power is dissipated during the transition period in the transistor. If the transistor is driven ... current generator, the emitter current is concentrated toward the ... of minimum base width. If no provisions are made to limit the colle... current, an alloying process starts, and in the minimum-width bas... ...n a p-type channel develops, resulting in a lasting collector-emitter short.

A mathematical analysis has been carried out in terms of a unidimensioned model. It was assumed that base width of the transistor is reduced considerably but at one spot. In one concrete case the temperature has been determined numerically in a minimum-width base region as a function of time. The minimum base width was assumed to be 1/5 of the nominal base width. The computations have shown, that only a few usecs are needed to reach a temperature of ~~more~~ several hundred centigrades in the minimum width base region.

To characterize the transistors from the point of view of thermal stability the ratio of equivalent base width /which may be computed from the cutoff frequency of the common-base-connected transistor/ to minimum base width wase introduced. The minimum base width may be determined by measuring the punch-through and avalanche-breakdown voltage.

The value, characteristic for the non-uniformity of transistor base width, may be expressed as follows:

$$\eta = \frac{W_e}{W_m}$$

where /W_e = equivalent base width, w_m = minimum base width/.

Transistors of the same type, having different η-factors, have been operated in pulse circuits and the case temperature has been measured. As a result of increasing the average power across the transistor, the case temperature has been successively elevated. In each case the temperature has been determined, at which thermal instability of the transistor took place. The transistor was preserved from damage by means of a resistor connected into the collector circuit.

Some transistors showed a behaviour similar to that of gaseous discharge tubes. They possessed $\eta = 4.2$, i.e. an extremely high non-uniformity of base width.

The results of the measurements are shown in the figure.

Subsequent to the pulse examinations all the transistors have been placed in thermostats and heated up to 85 °C. Dc voltages, equal to those present in pulse operation during "off" condition, have been applied to the terminals of the transistors. The transistors run without exception at this static operating point for a long time stably at 85 °C.

The examinations reported were carried out on alloy-type junction transistors.

Conclusions

The factor η which can be measured without damaging the transistor seems to be an important characteristic of transistor reliability. The "mysterious" causes of transistor failure, heretofore inexplicable, may be understood, (apart from surface phenomena), on the basis of the above considerations.

A more detailed description of the results will be published in the "Tungsram Technische Mitteilungen" in the near future.

Budapest, 20 July, 1962.

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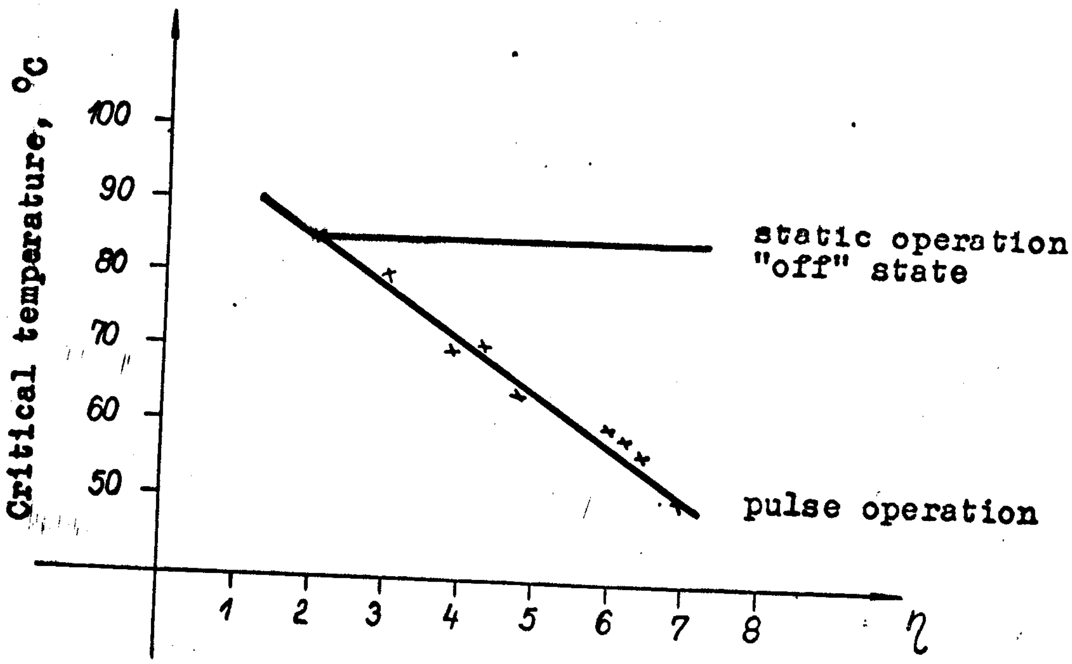
Critical temperature, °C
100
90
80
70
60
50
1
2
3
4
5
6
7
8
η
static operation
"off" state
pulse operation